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The environmental Kuznets curve model for greenhouse gas emissions in Canada

Edward Olale [a], Thomas O. Ochuodho [b, *], Van Lantz [c], Jafar El Armali [d]

[a] University of New Brunswick, Department of Economics, PO Box 4400, Fredericton, NB E3B 5A3, Canada
[b] University of Kentucky, College of Agriculture, Food and Environment, Department of Forestry and Natural Resources, 208A Thomas Poe Cooper Building, 730 Rose St, Lexington, KY 40546-0073, United States
[c] University of New Brunswick, Faculty of Forestry and Environmental Management, PO Box 4400, Fredericton, NB E3B 6C2, Canada
[d] Western University, Department of Economics, Faculty of Social Science, Western University, 1151 Richmond Street N, London, ON N6A 5C2, Canada

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ABSTRACT

This paper tests for the applicability of the Environmental Kuznets Curve (EKC) hypothesis at the Canadian and provincial/territorial levels using greenhouse gas emissions as an indicator for environmental degradation. The hypothesis is tested using provincial and territorial panel data from 1990 to 2014. The results vary depending on the econometric estimation method. The pooled regression results are mixed, with the EKC hypothesis confirmed at the Canadian level and in half of the provinces and territories. However, the fixed-effects regression results confirm the EKC hypothesis at the Canadian level and in all provinces and territories. The results also highlight the significance of technological change and province/territory specific characteristics in determining the level of greenhouse gas emissions.
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1. Introduction

Climatic change has become a topical issue across the world. Scientists place it at the top of the list of problems that humans need to deal with in current times (Fisher and Le, 2014; Kaivo-oja et al., 2016). There is also a consensus that human activities are causing recent global warming (IPCC, 2014; Cook et al., 2016). Consequently, various countries and jurisdictions are trying to identify the best policies that can drive down greenhouse gas (GHG) emissions in order to slowdown climate change. For instance, in 2015, the Conference of the Parties (COP 21) in Paris, France adopted what is commonly known as the Paris Agreement aimed at strengthening the global response to the threat of climate change (UNFCCC, 2015). One way of determining the effectiveness of environmental policies is through the Environmental Kuznets Curve (EKC). The EKC hypothesis posits that environmental damage first increases with income (GDP per capita), then declines. In other words, GDP per capita (income) and pollution per capita have an inverted U-shaped relationship (Stern, 2004, 2014; Kaika and Zervas, 2013; Sephton and Mann, 2016; Uchiyama, 2016).

Greenhouse gas can be defined as any gas that absorbs infrared radiation in the atmosphere (Environmental Protection Agency, 2015). In 2012, the most significant GHG emitted by human activities was carbon dioxide (CO_2) of about 82%, followed by methane (CH_4) of about 9%, nitrous oxide (N_2O) of about 6% and fluorinated gases (F–gases) of about 3% (Villoria-Saez et al., 2016). These gases are associated with increased economic activity. Although there are natural causes for GHG emissions, human contribution has grown significantly in the last century mainly due to the discovery and increased usage of fossil fuels in various economic activities (Belbute and Pereira, 2015). GHGs are known to cause global warming and surface temperature is projected to rise over the 21st century under all assessed emission scenarios (IPCC, 2014). The rising temperature will have an impact on marine life, forest productivity, agriculture productivity, human health, recreational activities, and other aspects of the economy (Ochuodho and Lantz,

* Corresponding author.
E-mail addresses: Edward.Olale@unb.ca (E. Olale), thomas.ochuodho@uky.edu (T.O. Ochuodho), vlantz@unb.ca (V. Lantz), jelarmal@uwo.ca (J. El Armali).

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2014; Environment and Climate Change Canada, 2016). These impacts will become more severe, unless concerted efforts to reduce GHG emissions are undertaken.

The purpose of this study is to test the relationship between GHG emissions per capita (a measure of environmental degradation) and GDP per capita at the Canadian and provincial/territorial levels over the time period between 1990 and 2014. It should be noted that GHG emissions alone as single environmental degradation indicator is not a fair reflection of the overall state of the environment in Canada.[1] GHG emissions should therefore be interpreted as a proxy for the overall state of the environment. The data period 1990–2014 was chosen for the analysis due to data availability. We chose the data period 1990–2014 given that was the timeframe we were able to get reliable data for this analysis. The goal is to test the validity of the EKC hypothesis and whether it applies to Canada and her provinces and territories. The study also aims to identify other factors influencing GHG emissions per capita. The study makes a methodological contribution by undertaking analysis using both pooled and fixed-effects regression models. Fixed-regression, as opposed to pooled regression, makes it possible to capture the province/territory specific characteristics. Capturing these characteristics is necessary given the vastness of Canada and the differences of climate change policies across provinces and territories.[2] The predictive power of the estimated models is also assessed using historical data. The paper is organized as follows. Section 2 describes the data and the variables, and specifies the EKC models to be estimated. Section 3 presents and discusses results. The last section summarizes the key findings, identifies areas of further research, and provides the policy implications of the study.

2. The EKC theory

The basic principle behind the EKC theory is that at early stages of development, higher economic growth results in environmental degradation. However, beyond a certain point, higher economic growth may actually result in environmental improvements (Stern, 2004). According to Fig. 1, there are three stages of development in an economy, pre-industrial economy (mainly the primary sector), industrial economy (secondary sector) and post-industrial economy (tertiary sector, services). The EKC hypothesis posits that in the early stages of economic growth, when primary production dominates, there is an abundance of natural resource stock and a limited generation of wastes because of limited economic activity. In the course of development and through industrialization, there occurs a significant depletion of natural resources and wastes accumulate. During this phase, there is a positive relationship between income or economic growth (per capita) and environmental degradation. At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology, and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation (Stern, 2004; Kaika and Zervas, 2013).

In a typical EKC curve (Fig. 1), the relationship between

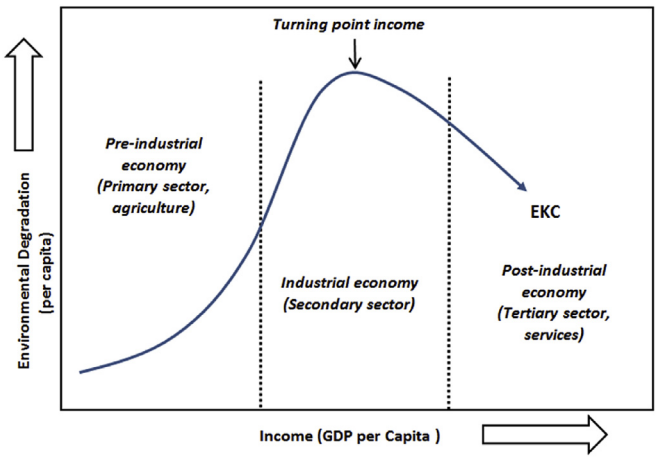

Fig. 1. EKC hypothesis, Adopted from Kaika and Zervas (2013).

environmental degradation (per capita) and income (per capita) is plotted as an inverted U and is similar to the original curve proposed by Simon Kuznets (Kuznets, 1955) concerning the relationship between income inequality and economic growth. The turning point in Fig. 1 represents the level of income beyond which environmental degradation begins to decline. In Fig. 1, the dependent variable on the vertical axis is an indicator of environmental degradation, which is GHG emissions in the current study. The independent variable on the horizontal axis is income (per capita) which is calculated by dividing the Gross Domestic Product (GDP) with the population of the economy. In addition to income, other factors not shown in Fig. 1 which can influence GHG emissions include trade, technological change, natural resource abundance, prevailing pollution policies, and so on. Changes in these factors can shift the EKC curve.

The EKC hypothesis is critical to understanding the developmental path of a nation in relation to its environment. How the effects of economic development dictate environmental changes can be found through the study of the EKC (Miah et al., 2010). However, no study exists for the EKC at the provincial/territorial level in Canada (disaggregated level), to the best of our knowledge. Given the diversity of Canadian provinces and territories, in terms of their energy production and consumption[3] it is important to fill this research gap.

There are many studies estimating the EKC for different countries and regions around the world. For instance, Shafik (1994) finds evidence of the EKC hypothesis using parametric estimation methods (where data is required to fit a normal distribution) on a large number of countries over time. The author uses income, technology and location-specific characteristics such as residential vs. commercial as environmental indicators. As well, Baiocchi and di Falco (2001) use emission per capita of three important air pollutant: sulphur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen dioxide (NO_2) and find support for the EKC hypothesis using nonparametric estimation methods (where data is not required to fit a normal distribution).

Balin and Akan (2015) use CO_2 emission per capita, patent applications of residents, research and development expenditures (%

[1] In addition to climate indicators (such as GHG emissions), other environmental indicators are air quality indicators (e.g., sulphur oxides, nitrogen oxides, volatile organic compounds, ammonia, carbon monoxide, and fine particulate matter), water quality indicators (e.g., mercury, lead, and cadmium), and wildlife and habitat indicators (e.g., biodiversity, biological resources, and protected areas).

[2] British Columbia, Alberta, Ontario and Quebec, representing more than 80 per cent of the population, have already introduced carbon pricing systems (carbon tax, cap-and-trade or both). Most other provinces are working to do the same (Environment and Climate Change Canada, 2017).

[3] Provincial/territorial production of energy (% of GDP) by 2014 are as follows: British Columbia (4.4), Alberta (21.7), Saskatchewan (17.9), Manitoba (5.8), Ontario (2.5), Quebec (4.2), New Brunswick (7.4), Nova Scotia (−), Prince Edward Island (3.4) Newfoundland and Labrador (19.7), Yukon (1.8), Northwest Territories (6.8), Nunavut (no data) (Natural Resources Canada, 2014).

Fig. 2. Map of Canada, Adopted from https://en.wikipedia.org/wiki/Provinces_and_territories_of_Canada.

of GDP), and industry (% of GDP) indicators and find an N-shaped relationship between CO_2 emissions and GDP per capita using panel data for 27 developed countries over the period 1997–2009. However, their results do not support the EKC hypothesis, which implies that environmental degradation cannot be solved automatically by economic growth. Galeotti et al. (2006), on the other hand use quantity of pollutants as environmental indicators and conclude that evidence supporting the EKC hypothesis for CO_2 emissions is mixed.

In addition, a few studies have tested the EKC hypothesis for Canada. For example, Lantz and Feng (2006) use a five-region panel data over the period 1970–2000. The authors find that GDP per capita is unrelated to CO_2, that an inverted U-shaped relationship exists with population, and that a U-shaped relationship exists with technology. Thus, technological and population changes are supported over the commonly hypothesized environmental Kuznets curve for affecting CO_2 emissions from fossil fuel use in Canada. Likewise, He and Richard (2010) do not find support for the EKC hypothesis for CO_2 emissions in the Canadian context. The authors argue that their results could be interpreted as indicating that the oil shock of the 1970s has had an important impact on progress towards less polluting technology and production.

However, Hamit-Haggar (2012), using the fully modified OLS technique, finds evidence of the EKC hypothesis for GHG emissions for a panel of high-polluting industries (energy-intensive) in Canada. Ajmi et al. (2015) also find evidence supporting the direct relationship between energy consumption and GDP in Canada which in turn reflects on the GHG emissions level. Most recently, Gill et al. (2018) evaluate the relevancy of the EKC hypothesis to the global environmental problems. The authors conclude that the EKC growth strategy "grow now clean later" is too much resource intensive and has huge environmental costs that this planet may not be able to absorb in the future. The study concludes that since energy is the most important determinant of pollution, therefore, governments should frame a special policy for "renewable energy" by taxing fossil fuels and subsidizing renewables.

3. The Canadian economy

Canada is a country in the northern part of North America. Its ten provinces and three territories extend from the Atlantic to the Pacific and northward into the Arctic Ocean, covering 9.98 million square kilometres, making it the world's second-largest country by total area and the fourth-largest country by land area (The World Factbook, 2017). The provinces are Alberta (AB), Ontario (ON), Quebec (QC), Saskatchewan (SK), British Columbia (BC), Manitoba (MB), Nova Scotia (NS), New Brunswick (NB), Newfoundland and Labrador (NL), and Prince Edward Island (PE). The territories are Northwest Territories (NT), Nunavut (NU), and Yukon (YT). In this study all the three territories in the northern part of the country are grouped together under "Territories", due to the nature of the data and information available (Fig. 2).

Canada has the seventh-largest economy in the world. Since the end of the World War II (1945), the economy has transformed from a rural economy, based on agriculture and natural resources to a more urban economy with services providing the main economic output. The nation has an expansive infrastructure, and modern factories and manufacturing plants. As well, there is an abundance of natural resources, including petroleum, natural gas, metals and minerals, forests, fish and agricultural land. Over the past decade, Canada has also emerged as one of the leading nations in the high-tech and computer industry (Encyclopedia of the Nations, 2017).

The Canadian economy varies greatly across provinces and territories. The province of ON is the largest in population and is the nation's main industrial center. About half of all Canadian manufactured goods are produced in ON, with automobiles and car parts being the main manufacturing industry. Other industries in ON include chemicals, aerospace, steel, and food processing. The province of QC is the second largest in population and is has a large industrial base of pharmaceuticals, aerospace products, and telecommunication companies. Atlantic Canada (NS, NB, NL and PE), mostly consists of natural resources-based industries (such as fishing, farming, forestry and mining), with a significant oil and gas industry in NL. The plains (or "prairie") provinces of AB, MB, and SK have four-fifths of Canada's agricultural lands. They are also the main contributor to mining and fuel production. AB itself provides 90 percent of the nation's energy exports and is the home of Canada's oil and natural gas industry. In the Province of BC (in the Pacific Northwest), forestry and tourism have been traditionally the main industries, but financial services and high-technology industries have grown dramatically over the past decade. The Northern territories are home to Canada's Native American population, where mining is the principal industry. However, traditional hunting, fishing and trapping also provide a substantial part of the region's economy (Citizenship and Immigration Canada, 2012).

The differences in industries across Canadian provinces and territories have implications on energy generation and GHG emissions. SK and AB have higher per capita emissions due to their reliance on coal-fired electricity generation as well as oil sands and heavy oil production. In contrast, BC, ON and QC have lower per capita emissions as they rely mostly on hydro-electric or nuclear energy sources and have relatively few large industrial emitters (Boothe and Boudreault, 2016).

The level of CO_2 emission is dependent on the type (source) of energy used, either fossil or renewable. This is what is known as the emission factor, i.e. the weight of CO_2 emission per unit of fuel type burnt. At the national level, Canadian energy production in 2014 came from the following sources: crude oil (43%), natural gas (33%), coal (8%), hydro (7%) other renewables such as wind, solar, biomass (4%), nuclear (2%) and natural gas liquids (3%) (Natural Resources Canada, 2014).

4. Data and methodology

This study is based on panel data (cross-sectional time-series data) for Canadian provinces and territories from 1990 to 2014. The data therefore consists of 11 panels (10 provinces and Territories) over a period of 25 years, with a total of 275 observations. Annual GHG emissions are obtained from Environment and Climate Change Canada. GDP, Consumer Price Index (CPI) and population are obtained from Statistics Canada, while trade data is obtained from Innovation, Science and Economic Development Canada. The dependent variable in our model is GHG emissions per capita (measured in tonnes) – the environmental degradation indicator. On the other hand, GDP per capita (measured in thousands of constant 2007 dollars), GDP per capita squared, trade openness[4] (measured as the sum of exports and imports as a percentage of GDP) and time trend are used as explanatory variables in our models. Each province/territory is represented by a dummy variable in the panel data. An "interactive dummy variable" is also included in each model, equal to provincial/territorial dummy multiplied by GDP for each province/territory. Overall, the panel data set consists of 27 variables. All the models estimated are based on the quadratic form to reflect the inverted-U shape for the EKC hypothesis. The first EKC model (Model 1) is specified as:

$$\frac{GHG\,emissions_{it}}{Population_{it}} = \alpha_i + \beta_1\left(\frac{GDP_{it}}{Population_{it}}\right) + \beta_2\left(\frac{GDP_{it}}{Population_{it}}\right)^2 + \delta_i IT_i + \varepsilon_{it} \quad (1)$$

Where, i represents the province/territory and t denotes the year; $GHG\,emissions_{it}/Population_{it}$ represents GHG emissions per capita; $GDP_{it}/Population_{it}$ represents GDP per capita; α_i is the province/territory intercept; β_1 and β_2 are coefficients for GDP per capita and GDP per capita squared, respectively; IT_i represents interaction terms for GDP and provincial/territorial dummies (interactive dummy variables); δ_i are coefficients for the interactive dummy variables; and ε_{it} is the random error term. If the estimates are such that β_1 is positive, β_2 is negative, $|\beta_1| > |\beta_2|$, and both coefficients are statistically significant, then the EKC hypothesis is supported at the Canada level. However, the EKC hypothesis holds at the provincial or territorial level if the interactive dummy variable for a given province/territory is also statistically significant. The model is re-estimated after adding trade openness in Model 2, and trade openness and time trend in Model 3 as explanatory variables as follows:

$$\frac{GHG\,emissions_{it}}{Population_{it}} = \alpha_i + \beta_1\left(\frac{GDP_{it}}{Population_{it}}\right) + \beta_2\left(\frac{GDP_{it}}{Population_{it}}\right)^2 + \beta_3 Trade_{it} + \delta_i IT_i + \varepsilon_{it} \quad (2)$$

$$\frac{GHG\,emissions_{it}}{Population_{it}} = \alpha_i + \beta_1\left(\frac{GDP_{it}}{Population_{it}}\right) + \beta_2\left(\frac{GDP_{it}}{Population_{it}}\right)^2 + \beta_3 Trade_{it} + \beta_4 Trend + \delta_i IT_i + \varepsilon_{it} \quad (3)$$

Following past studies, all the three models are estimated using pooled[5] and fixed-effects regressions. Pooled regression restricts the estimated intercept term to be identical across provinces and territories (i.e. $\alpha_i = \alpha$). Conversely, fixed-effects regression allows the estimated intercept term to be unique for each province/territory (i.e. each intercept is α_i). These intercepts capture province/territory specific factors including geography, resource endowments, land area, business climate, or government policies that may affect the GHG emissions (Lantz and Feng, 2006). If these variables are correlated with any of the independent variables, their omission from the models will generate biased and inconsistent estimates (Greene, 2008). Past EKC studies generally prefer the fixed-effects regressions. However, Both results are presented in this paper to facilitate comparison.

It is worth noting that in calculating trade openness, nominal trade figures are divided by CPI to obtain real trade values which are then divided by real GDP. Since the territories are grouped together, weighted average CPI is calculated for the group as follows:

[4] This variable is also referred to as "trade intensity" in past studies such as Heil and Selden (2001). For Canadian provinces and territories, it only includes international trade and does not include trade among proveniences and territories.

[5] Pooled regressions are estimated with robust standard errors to address any potential heteroskedasticity.

Table 1
Descriptive statistics of the variables used in the study.

Geography	Variable	Mean	Std. Dev.	Min	Max	% change (1990–2014)
Canada	GHG emissions (tonnes per capita)	22.42	1.19	20.59	24.25	−6.97
	GDP per capita ($000)	42.63	5.07	34.60	49.02	36.68
	Trade openness (%)	54.00	7.46	38.95	67.77	29.80
AB	GHG emissions (tonnes per capita)	71.08	4.07	63.60	77.23	−2.90
	GDP per capita ($000)	65.90	7.79	52.01	75.64	44.17
	Trade openness (%)	35.19	7.05	23.13	48.79	90.66
ON	GHG emissions (tonnes per capita)	15.97	1.84	12.42	18.06	−29.73
	GDP per capita ($000)	42.65	4.49	35.08	47.32	28.29
	Trade openness (%)	75.91	13.13	55.04	99.40	21.07
QC	GHG emissions (tonnes per capita)	11.62	0.78	10.07	12.73	−20.94
	GDP per capita ($000)	36.05	4.17	29.30	40.55	33.24
	Trade openness (%)	43.64	6.05	32.23	56.33	19.77
SK	GHG emissions (tonnes per capita)	63.46	7.59	44.58	70.09	50.45
	GDP per capita ($000)	46.91	6.27	36.48	56.13	49.67
	Trade openness (%)	44.70	12.81	26.34	69.07	147.93
BC	GHG emissions (tonnes per capita)	15.19	0.98	13.54	16.51	−15.73
	GDP per capita ($000)	40.97	4.57	35.54	48.60	32.86
	Trade openness (%)	38.07	4.41	31.36	48.13	−7.00
MB	GHG emissions (tonnes per capita)	17.33	0.74	15.81	18.48	−0.78
	GDP per capita ($000)	37.94	4.63	31.25	44.31	36.00
	Trade openness (%)	45.29	8.52	26.54	55.22	99.02
NS	GHG emissions (tonnes per capita)	22.16	1.83	17.60	25.76	−19.89
	GDP per capita ($000)	33.10	4.02	27.79	38.14	33.18
	Trade openness (%)	35.11	5.15	26.11	42.32	3.40
NB	GHG emissions (tonnes per capita)	25.01	3.13	19.74	30.67	−10.92
	GDP per capita ($000)	33.46	4.63	26.28	38.69	41.79
	Trade openness (%)	62.20	15.73	37.43	90.36	89.78
NL	GHG emissions (tonnes per capita)	18.23	2.66	12.90	22.71	20.98
	GDP per capita ($000)	43.10	10.02	29.28	57.10	74.09
	Trade openness (%)	35.61	14.63	13.51	65.51	121.93
PEI	GHG emissions (tonnes per capita)	14.52	0.84	12.19	15.75	−17.88
	GDP per capita ($000)	29.64	4.32	22.82	35.34	54.86
	Trade openness (%)	16.32	3.66	8.95	21.69	107.56
Territories	GHG emissions (tonnes per capita)	23.11	3.58	16.95	30.10	−29.45
	GDP per capita ($000)	57.77	10.45	43.50	72.69	39.81
	Trade openness (%)	20.33	8.62	5.79	33.23	88.01

Note: GDP per capita is measured in constant 2007dollars.

$$CPI_t \text{ for Territory} = \frac{\sum_{k=1}^{3}(Population_{kt} * CPI_{kt})}{\sum_{k=1}^{3} Population_{kt}} \quad (4)$$

where k represents a Canadian territory (i.e., NT, NU or YT). However, CPI data is available only for the main city in each territory, so this was used as an approximate measure of the overall CPI in each territory even though an average CPI would be appropriate. To allow for econometric estimation using panel data, stationarity was tested using Levin-Lin-Chu unit-root test and all variables were found to be stationary. In addition, endogeneity of GDP is not a major concern in this study as the causality running from GDP to GHG emissions has been found to be unidirectional in Canada (Hamit-Haggar, 2012). Put differently, GDP influences GHG emissions and not vice versa.

The predictive power of the models is measured by the mean absolute percentage error (MAPE). MAPE is a widely used measure of forecast accuracy, due to its advantages of scale-independency and interpretability (Byrne, 2012; Myttenaere et al., 2016). In the current study, it is used to compare prediction accuracy across various estimation methods, model specifications, and geographical areas. MAPE is calculated as follows:

$$MAPE = \frac{100}{n}\sum_{t=1}^{n}\left|\frac{A_t - P_t}{A_t}\right| \quad (5)$$

Where A_t is the actual value, P_t is the predicted value, and n is the number of data points. For each year, the difference between A_t and P_t is divided by the Actual value A_t. The absolute value in this calculation is summed for every predicted point in time and divided by the number of fitted points n. The summation is multiplied by 100 to generate a percentage error (MAPE).

Table 1 presents the descriptive statistics of the variables used in the regressions (i.e. GHG emissions per capita, real GDP per capita, and trade openness). GHG emissions per capita for Canada as a whole varied between 21 and 24 tonnes per year between 1990 and 2014. The emissions increased between 1990 and 2000, mainly in the oil producing provinces (AB, SK, and NL) and the Maritimes (NB, NS and PE).[6] However, GHG emissions per capita decreased between 2000 and 2014, with declines in all provinces and territories. This is the period after Canada signed the Kyoto Protocol in 1998[7] In addition, according to Environment Canada (2013), fossil fuel CO_2 emissions, a major component of GHG emissions, fell in 2008 and 2009 due to the global recession. This explains the decline in GHG emissions per capita by 4% and 7% in 2008 and 2009, respectively. Per capita emissions vary widely across provinces and territories, with 67 tonnes in AB and SK in 2014 compared to 10–14 tonne range in BC, ON, PE and QC in the same year. This is a sign that province specific characteristics are relevant in explaining GHG emissions.

[6] It should be noted that population in the Maritimes declined significantly between 1994 and 2000, which could have resulted in higher GHG emissions per capita.

[7] The timeframes (1990–2000 and 2000–2014) used were chosen based on the century cuff-off (i.e., 20st century vs. 21st century). In addition, a pattern was observed where GHG emissions per capita across Canada peaked in 2000 and then declines thereafter.

Table 2
Summary of the regression results[a,b].

Variable	Pooled Regression			Fixed-Effects Regression		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	−4.847 (−1.402)	−5.279 −1.493	−27.540*** (−9.245)	−26.672*** (−3.299)	−26.581*** (−3.273)	−42.608*** (−6.029)
GDP per capita	1.340*** (7.395)	1.353*** (7.386)	1.931*** (13.905)	3.186*** (6.272)	3.177*** (6.197)	3.182*** (7.325)
(GDP per capita)^2	−0.014*** (−6.619)	−0.015*** (−6.656)	−0.015*** (−9.591)	−0.028*** (−6.406)	−0.028*** (−6.356)	−0.025*** (−6.680)
Trade openness	–	0.044** (2.064)	−0.009 (−0.445)	–	0.003 (0.153)	−0.005 (−0.247)
Trend	–	–	−0.602*** (−9.284)	–	–	−0.537*** (−9.978)
IT_{AB}	0.758*** (29.231)	0.751*** (29.032)	0.706*** (35.755)	0.282*** (2.886)	0.281*** (2.862)	0.370*** (4.420)
IT_{ON}	−0.240*** (−11.134)	−0.305*** (−8.262)	−0.053 (−1.258)	−1.052*** (−5.788)	−1.048*** (−5.690)	−0.509*** (−3.081)
IT_{QC}	−0.364*** (−15.963)	−0.406*** (−15.164)	−0.058 (−1.342)	−1.310*** (−5.673)	−1.306*** (−5.613)	−0.617*** (−2.952)
IT_{SK}	0.798*** (35.944)	0.769*** (27.267)	0.918*** (28.304)	0.407*** (3.093)	0.405*** (3.056)	0.750*** (6.387)
IT_{BC}	−0.261*** (−12.623)	−0.289*** (−12.655)	−0.053* (−1.679)	−0.989*** (−5.499)	−0.983*** (−5.329)	−0.410** (−2.465)
IT_{MB}	−0.209*** (−9.477)	−0.250*** (−9.376)	0.058 (1.440)	−1.083*** (−5.253)	−1.083*** (−5.242)	−0.466** (−2.509)
IT_{NS}	−0.050* (−1.792)	−0.085*** (−2.895)	0.327*** (6.937)	−1.267*** (−5.038)	−1.261*** (−4.956)	−0.515** (−2.259)
IT_{NB}	0.033 (1.052)	−0.039 (−1.089)	0.406*** (7.049)	−1.135*** (−4.652)	−1.141*** (−4.621)	−0.499** (−2.280)
IT_{NL}	−0.147*** (−7.239)	−0.172*** (−7.566)	0.012 (0.498)	−0.572*** (−3.885)	−0.572*** (−3.879)	−0.452*** (−3.602)
IT_{PE}	−0.263*** (−9.606)	−0.275*** (−10.768)	0.212*** (4.276)	−1.622*** (−5.863)	−1.618*** (−5.812)	−0.895*** (−3.627)
Adjusted R-squared	0.980	0.980	0.986	0.986	0.986	0.990
F test: overall significance	744.30***	720.95***	993.45***	869.12***	828.11***	1109.36***
F test: fixed-effects	–	–	–	14.04***	13.43***	9.78***

The intercept for the fixed-effects regression includes the province effects (10 provincial dummies).
[a] Values in parenthesis under coefficient estimates represent t-statistics.
[b] ***, **, and * indicate statistical significant at the level 1%, 5%, and 10%, respectively.

Over the 25 year period (1990–2014), the real GDP per capita for Canada varied from a low of $35,000 per year in the early 1990s to a high of $49,000 in 2014 (an increase of 37%). The growth in real GDP per capita is highest in NL, PE, SK, AB, NB, and the Territories (over 37%) and lowest in MB, QC, NS, BC and ON (below 37%). Trade openness for Canada (a measure of trade liberalization) increased from a low of 39% in 1991 to a high of 68% in 2000. This is followed by a reduction between 2000 and 2014, with trade openness standing at 53% in 2014. The highest growth in trade openness is observed in SK, NL, PE, MB, AB, NB, and the territories (over 30%), with the lowest growth in ON, QC, NS and BC (below 30%).

5. Results and discussion

Results of the pooled and fixed-effects regressions are summarized in Table 2. The results provide support for the EKC hypothesis for GHG emissions at the Canadian level. This is because the coefficients for GDP per capita (β_1) and GDP per capita squared (β_2) are statistically significant in all models and have expected signs (i.e. $\beta_1 > 0$, $\beta_2 < 0$, and $|\beta_1| > |\beta_2|$). The three models have good explanatory power as shown by the adjusted R-squared of 0.98–0.99 and statistically significant F-values in the test of overall significance. However, in both estimation methods, adding time trend in Model 3 led to an improvement in the adjusted R-squared compared to models 1 and 2. This may be an indication that Model 3 has better explanatory power than the first two models. Furthermore, fixed-effects regression generates higher adjusted R-squared than the pooled regression in all three models. This confirms why previous EKC studies prefer fixed-effects regression to the pooled regression (Lantz and Feng, 2006). Overall, Model 3 estimated through fixed-effects regression generates the best fit for the data. Under the fixed-effects regression, 11 out of 12 explanatory variables included in Model 1 are statistically significant at 10% or better. This is compared to 12 out of 13 variables and 13 out of 14 variables in Models 2 and 3, respectively. In addition, all the fixed-effects are statistically significant in the three models. Overall, more variables are statistically significant in the fixed-effects regressions than in the pooled regressions.

Trade openness is statistically insignificant in Model 3 estimated by pooled regression and in all the fixed-effects regressions. The statistical insignificance of trade openness is different from past studies who find the variable negatively related to per capita CO_2 emissions, especially in higher income countries (Heil and Selden, 2001; Kais and Sami, 2016; Jebli et al., 2016). It should be noted that the measure for trade openness does not include trade among provinces and territories which may underestimate total trade. The time trend, which is only included in Model 3, is found to be negative and statistically significant at the 1% level in both the pooled and fixed-effects regressions. The negative relationship holds even with inclusion of a quadratic term for time trend.[8] This implies that technological change is inversely related to GHG emissions per capita. The result matches theoretical expectations (see Stern, 2004). Canadian consumers and producers have been adopting more efficient practices and equipment over time. In addition, their knowledge about their choices and the impacts of those choices on the environment is improving (Environment and Climate Change Canada, 2016). As a result, the U-shaped relationship between time trend and CO_2 emissions per capita found by Lantz and Feng (2006) and He and Richard (2010) is not supported.

Results for the EKC hypothesis at the provincial/territorial level vary depending on the estimation method. Under the pooled regression, the interactive dummies are statistically significant at 10% or better in Models 1 and 2 in all provinces and territories except NB. However, in Model 3, the interactive dummies are statistically significant in AB, SK, BC, NS, NB, and PE (six out of 10 provinces[9]). This result confirms the EKC hypothesis in AB, SK, BC, NS, and PE (five out 10 provinces). The EKC hypothesis is however confirmed in all provinces and territories under the fixed-effects regression as all interactive dummies are statistically significant in all models.

The EKC hypothesis results found in this study confirms the results of Hamit-Haggar (2012) who found an EKC-type relationship between GHG emissions and economic growth in Canadian industrial sectors. The EKC has also been confirmed for Canada is

[8] This is not included in this paper, but is available from the authors upon request.
[9] The dummy variable for Territories is excluded in the regressions to avoid dummy variable trap.

the past, when the country is included in international panel data studies (Moomaw and Unruh, 1997; Dijkgraaf and Vollebergh, 2005; Volleberg et al., 2005). For instance, Moomaw and Unruh (1997) find evidence that Canada exhibits an EKC, presumably caused by the oil shock in 1970s. Dijkgraaf and Vollebergh (2005), and Volleberg et al. (2005), using a panel data of OECD countries, also find some evidence that an EKC exists for CO_2 emissions in Canada. However, these studies use models with few or no control variables, and only income is allowed to have a non-linear effect on CO_2 emissions. These restrictions are relaxed in the current study by including trade openness, time trend, and capturing province/territory specific characteristics through fixed-effects regressions. It is also difficult to predict CO_2 or GHG emissions using international panel models as Canada is often a small part of their samples.

Contribution to GHG emissions per capita varies by province and territory. As expected, AB and SK are found to be the major contributors to GHG emissions per capita as shown by the positive sign and strong statistical significance of their coefficients in all the models. This is in contrast to ON and QC which show negative and strong statistical significance on GHG emissions per capita. SK and AB's high levels of per capita emissions come from their reliance on coal-fired electricity generation as well as oil sands and heavy oil production. In contrast, ON and QC rely more on hydro-electric or nuclear electricity generation (Booth and Boudreaul, 2016).

The turning point of GDP per capita for each province/territory (measured in thousands of constant 2007 dollars) is calculated using the estimated coefficients under each model. This is the GDP per capita above which GHG emissions per capita begins to decline, assuming other variables are fixed. The turning point for each province/territory is calculated as follows, where i represents the province or territory:

$$\frac{GDP_i}{Population_i} = -(\beta_1 + \delta_i)/2\beta_2 \quad (6)$$

Table 3 below shows the turning point estimates. The differences in these points show that the provincial and territoriale specific characteristics are important in determining GHG emissions per capita. In addition, it can be noticed that while the estimated turning points are relatively close in Models 1 and 2, the estimation from Model 3 yields higher values. This is mainly because of time trend which is only included in Model 3. Pooled regressions that exclude time trend (Models 1 and 2) show that AB, ON, QC, BC, MB, NL and the territories have reached their turning point GDP per capita (have turning points within the sample range for GDP per capita). However, the pooled regression that includes time trend (Model 3) shows that only the territories has reached the turning point. The results of the fixed-effects regression are different. Models 1 and 2 show that all provinces and territories except SK have reached the turning point. However, Model 3 shows that only AB, NL and the territories have reached the turning point. Going by the 3rd model under fixed-effects regression, GDP per capita will have to increase in most Canadian provinces and territories before reaching the turning point. This implies that increases in GDP per capita cannot be relied upon as the sole source of GHG emission reduction. Specific GHG emission reduction policies are required.

Table 3
Turning point of annual GDP per capita ($000).

Geography	Pooled Regression			Fixed-Effects Regression		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
AB	73.63	72.04	86.23	61.14	61.08	70.23
ON	38.63	35.88	61.43	37.62	37.60	52.85
QC	34.25	32.44	61.26	33.07	33.05	50.72
SK	75.06	72.64	93.15	63.33	63.27	77.74
BC	37.87	36.42	61.41	38.72	38.75	54.80
MB	39.72	37.78	65.04	37.07	36.99	53.70
NS	45.28	43.43	73.85	33.84	33.84	52.72
NB	48.19	45.00	76.43	36.15	35.97	53.05
NL	41.87	40.45	63.54	46.08	46.00	53.97
PE	37.82	36.91	70.09	27.57	27.53	45.22
Territories	47.04	46.33	63.15	56.16	56.12	62.82

Table 4
Mean absolute percentage error (%).

Geography	Pooled Regression			Fixed-Effects Regression		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Canada	5.51	4.44	2.15	4.32	4.25	1.97
AB	6.20	6.15	4.26	3.61	3.61	2.54
ON	9.15	7.52	3.29	8.46	8.37	2.53
QC	4.59	3.45	6.52	3.27	3.22	5.76
SK	5.81	5.92	5.23	5.22	5.23	4.89
BC	3.51	2.56	7.43	2.98	2.93	5.95
MB	3.15	3.04	4.24	2.61	2.55	3.87
NS	7.69	6.72	5.01	5.19	5.17	3.86
NB	9.45	10.39	6.98	9.00	9.06	6.47
NL	13.07	12.57	6.39	7.23	7.22	6.67
PE	9.26	9.11	8.54	3.21	3.23	3.14
Territories	15.11	14.90	9.86	13.44	13.44	10.94

Table 4 presents the MAPE results calculated from the model regression results and historical values. The results show that the prediction error is lowest in the Model 3 estimated through the fixed-effects regression. MAPE generated from this model ranges from 2.1% for Canada as whole to 10.9% in the territories. Fig. 3 shows the actual versus predicted historical GHG emissions per capita for Model 3 estimated using fixed-effects regression. The graphs are presented for Canada as a whole, for each province, and for the territories. Overall, the historical values are predicted with an acceptable level of accuracy, a sign that the model can be effective when used to forecast future GHG emissions per capita, in the short-run when model parameters can be predicted reasonably. This observation is supported by the fact that Model 3 under the fixed-effects regression had the highest adjusted R-squared.

6. Conclusion

Overall, the results of this study support the EKC hypothesis at the Canadian level. However, results for the EKC hypothesis at the provincial/territorial level vary by estimation method. In particular, under the pooled regression, the EKC hypothesis is confirmed for AB, SK, BC, NS, and PE (five out 10 provinces). The hypothesis is however confirmed in all provinces and territories under the fixed-effects regression as all interactive dummies are statistically significant in all models. The time trend (which captures technological change) and the provincial/territorial specific characteristics are also found to influence GHG emissions per capita. In terms of provinces and territories, AB and SK have a positive and strong contribution to GHG emission per capita due their reliance carbon-intensive energy sources. The rest of the provinces (region-specific characteristics) generally have a negative impact on GHG emissions per capita.

Despite some of the insightful results from this analysis, a few caveats are worth noting. Although the findings show support for the EKC hypothesis using GHG emissions as an environmental degradation indicator, using other pollutants in the analysis may yield different results. In addition, the analysis in this study is bound by the time period in which data is available. If data is available for a longer period of time, then there would be sufficient

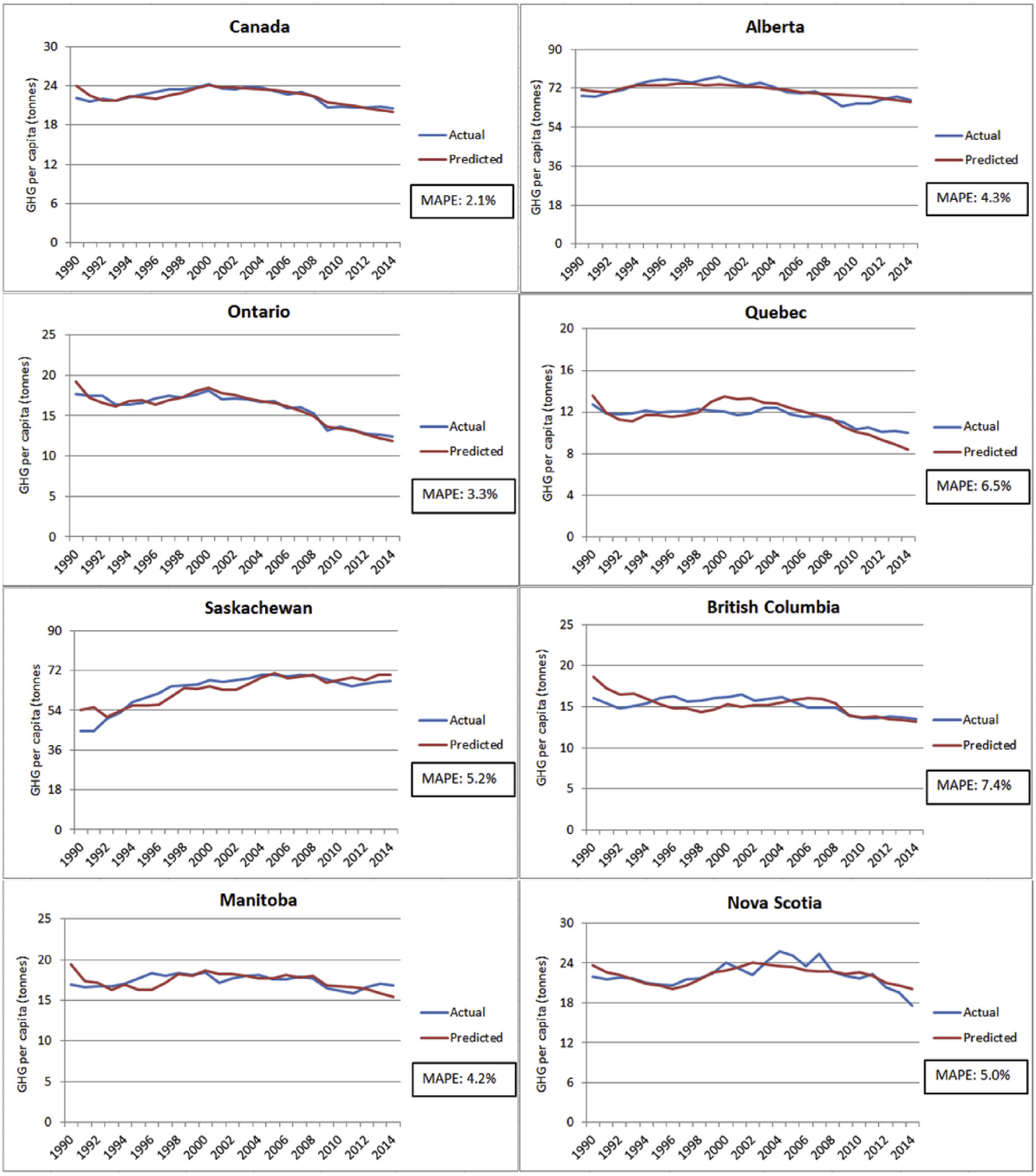

Fig. 3. Prediction of GHG emissions per capita by year using fixed-effects regression, Model 3, Prediction of GHG emissions per capita by year.

observations to estimate a separate model for each province/territory which may yield more accurate regression results. Since the current analysis is for aggregate GHG emissions, future studies can test the EKC hypothesis for individual GHGs (CO_2, methane, N_2O etc.), depending on data availability.

Despite the challenges noted above, this study is a good starting point in modelling GHG emissions in Canada. In particular, confirmation of the EKC hypothesis for GHG emissions in Canada provides a signal for future reductions in GHG emissions arising from increases in income. However, increased income cannot be the sole source of GHG emissions reduction. Specific GHG emission reduction policies are required. One such effort is the Pan-Canadian

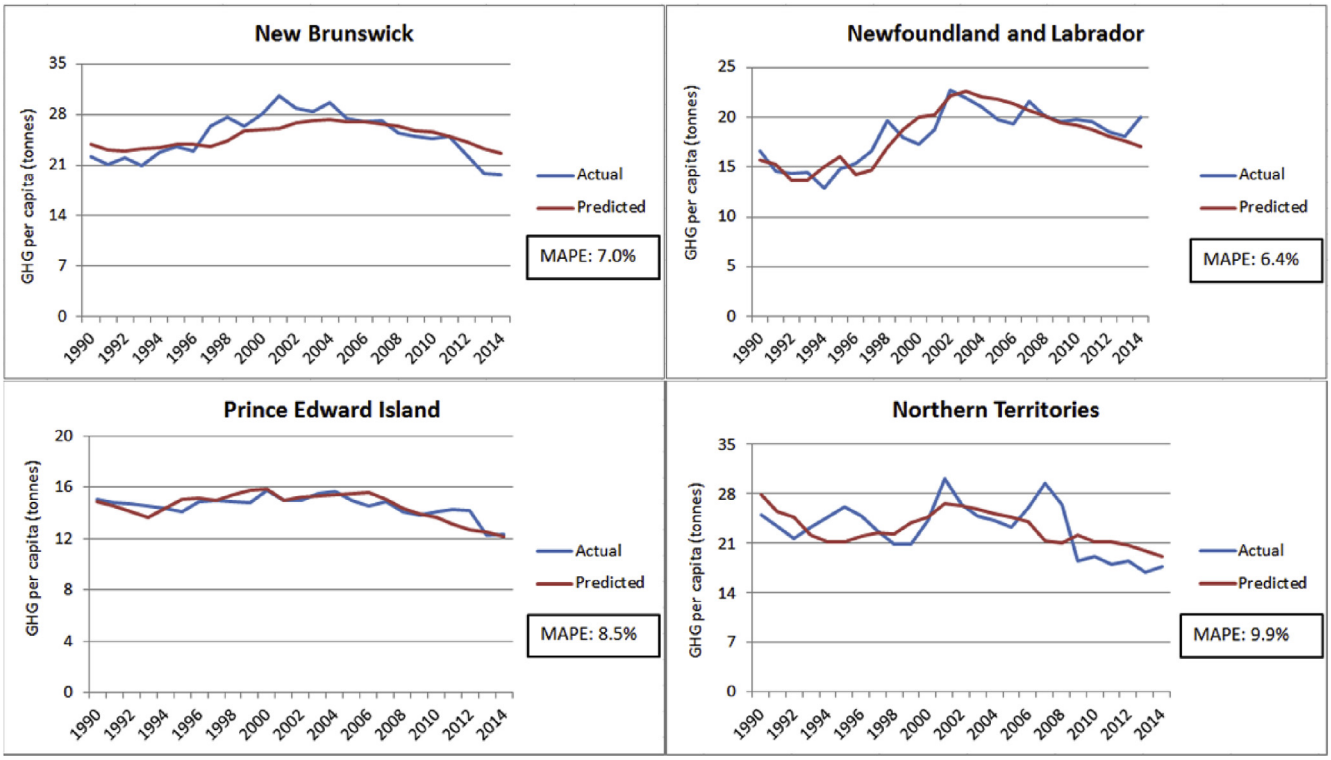

Fig. 3. (*continued*).

Framework on Clean Growth and Climate Change recently launched by the Canadian government to meet GHG emission reduction targets and grow the economy. The models developed in this study can be used to determine the impact of this framework on GHG emissions at the Canadian level, as well as in the provinces and territories. The models can also be used to forecast GHG emissions, in the short-run.

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